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Development and Initial Evaluation of an Acceptance Testing Procedure for Air Supply and Distribution Systems in New Army Facilities

by
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This document reports USA-CERL's efforts to develop a new acceptance test procedure for ensuring the energy efficiency of air supply and distribution systems in new Army facilities. The procedure was developed by interviewing heating, ventilating, and air-conditioning (HVAC) professionals, reviewing technical literature, and consolidating these findings into a simple, easy-to-use procedure. With this procedure, air supply and distribution system components can be identified and systematically checked for completeness, proper operation, and energy efficiency. Necessary data and efficiency calculations are identified and worksheets are used for recording this information. A glossary of possibly unfamiliar HVAC terms is included. An informal evaluation of the procedure showed that considerable engineering judgment may be needed to choose measurement methods and locations that will produce accurate data. The system's design also affects the ease or difficulty of performing the test. More extensive evaluations are necessary before the procedure can be recommended for use.

This work is part of an overall project to improve the installation and operation of HVAC systems in new Army facilities.

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FOREWORD

This work was performed for the Directorate of Engineering and Construction, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 4A162781AT45, "Energy and Energy Conservation"; Technical Area A, "New Construction Energy Design"; Work Unit 013, "Contracting, Construction, and Acceptance Testing for Energy Efficient Buildings." Mr. J. McCarty (CEEC-EE) was the HQUSACE Technical Monitor.

The work was conducted by the Energy Systems (ES) Division of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. G. R. Williamson is Chief, USA-CERL-ES. Jane Andrew, USA-CERL Information Management Office, was the technical editor.

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COL Carl O. Magnell is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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DEVELOPMENT AND INITIAL EVALUATION OF AN ACCEPTANCE TESTING PROCEDURE FOR AIR SUPPLY AND DISTRIBUTION SYSTEMS IN NEW ARMY FACILITIES

1 INTRODUCTION

Background

The correct installation and energy efficient operation of a new facility's heating, ventilating, and air-conditioning (HVAC) system can have a strong impact on the facility's overall energy consumption. New facilities should be designed and constructed with this in mind. Unfortunately, although current construction practices can produce functional HVAC systems that provide adequate heating and cooling, they do not guarantee that the systems are operating at maximum energy efficiency. Acceptance testing of a new facility's HVAC systems can become vital in ensuring the proper operation of an energy-efficient building. This step becomes even more important as the size and complexity of the building increases.

U.S. Army Corps of Engineers (USACE) field offices need new acceptance testing procedures that can verify HVAC systems are operating as designed and at maximum energy efficiency. Operations and maintenance personnel in Directorates of Engineering and Housing (DEHs) might also find such procedures useful for maintaining or improving the efficiency of existing HVAC systems. The procedures should test the HVAC system components that will accurately indicate how efficiently the system is performing. Just as important, these procedures must be easy for Corps field inspectors to use, even if they have only a minimum background in HVAC fundamentals.

As part of an ongoing effort to improve construction and acceptance testing of new facilities, to ensure that they are as energy efficient as possible, the U.S. Army Construction Engineering Research Laboratory (USA-CERL) has published two interim reports (IRs). USA-CERL IR E-86/05[1] identified the steps involved in the construction phase of the Military Construction, Army (MCA) process and discussed problems associated with producing energy-efficient new facilities. An example was also developed of an improved version of the "Testing, Adjusting, and Balancing" section of Corps of Engineers Guide Specification (CEGS) 15805.[2] The suggested improvements were intended to ensure energy-efficient operation of a new building's air supply and distribution system. USA-CERL IR E-88/02[3] surveyed the Corps' current construction procedures and literature on construction in the private sector. It was found that MCA phases other than construction affected a facility's final energy performance. In order to enhance the facility's energy performance, recommendations on improving various steps

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[1]Dale Herron, Dahtzen Chu, and Charles Burton, *Preliminary Recommendations for Improving the Construction and Acceptance Testing of Energy-Efficient Facilities*, IR E-86/05/ADA169913 (USA-CERL, June 1986).
[2]CEGS-15805, *Air Supply and Distribution Guide Specification* (USACE, December 1984).
[3]Dahtzen Chu, Charles Burton, and Mark Imel, *Identification of Ways to Improve Military Construction for Energy-Efficient Facilities*, IR E-88/02/ADA189632 (USA-CERL, December 1987).

of the MCA process were made. The report also documented a strong need for an HVAC acceptance test. In response to this need, initial steps were taken toward developing an acceptance test for air supply and distribution systems. These systems were chosen for the first test to be developed because they are used in many Corps facilities.

In future work, the acceptance test described in this report will be tested under controlled conditions to determine its accuracy and in the field to evaluate how easy it is to use; the procedure will be modified based on these results. Tests may also be developed for other HVAC components.

Objective

The objective of this phase of study was to develop and initially evaluate a draft acceptance test procedure for air supply and distribution systems. The purpose of this procedure is to ensure that the systems have been installed correctly and are operating efficiently.

Approach

1. To establish a body of information on HVAC systems, inspection checklists were compiled for many individual HVAC components that may require testing.

2. From these checklists, techniques for analyzing air supply and distribution system efficiency were analyzed, modified, and incorporated in a new acceptance test procedure.

3. The new acceptance test procedure was informally evaluated at an existing and a new Army facility to gauge its accuracy and ease of use.

4. Recommendations for refining and expanding the breadth of acceptance testing in new Corps facilities were developed.

The original approach also included monitoring actual construction projects to identify general types of deficiencies that could reduce a new facility's energy efficiency, but this step was eventually de-emphasized. This was due to extremely slow progress on the projects being monitored, in part, and to a realization that an effective acceptance test of a new facility's HVAC system would be more successful in ensuring efficient energy consumption.

Mode of Technology Transfer

After further testing and possible modification, this procedure will be transferred to the field as a field manual or engineering regulation. It is recommended that the procedure be referenced in CEGS-15805 and other appropriate guide specifications, so that design elements can be included to facilitate acceptance testing.

2 ACCEPTANCE TESTING REQUIREMENTS

After HVAC systems are installed in new Army buildings, they are tested, adjusted, and balanced (TAB) by the mechanical contractor or his subcontractor to ensure proper operation. The TAB results are recorded and given to the Corps field office in charge of the project.

If the readings recorded in the TAB reports are not within a reasonable range, the Corps will refuse to accept the building until the problems are corrected. Unfortunately, there are no procedures and standards the Corps can use to verify that the TAB results guarantee energy-efficient operation. Visual or functional checks or routine TAB work may not uncover efficiency problems that involve installation, engineering design, systems control, and compatibility between components. The lack of standardized acceptance test procedures based on systematic measurement, analysis, and documentation of performance data makes it hard to decide whether problems are caused by design errors or incorrect installation. This inadequacy was described at length in IR E-88/02.[4]

A working definition of the term "acceptance test" was given in IR E-88/02.[5] This definition has been made more concise:

> Acceptance testing of HVAC systems is a systematic procedure to be used by U.S. Army Corps of Engineers representatives and inspectors to evaluate HVAC components of new construction projects. The procedure will ensure that design and installation is in accordance with accepted minimum energy efficient standards and specifications.

This definition forms the basis for USA-CERL's current and future development of acceptance test procedures.

In developing an acceptance test procedure, two goals were set: the test (1) should be easy to use, even for personnel with limited HVAC backgrounds, and (2) should require only simple calculations. The factors considered in developing usable procedures included:

- Time required to perform the procedure
- Training and experience of personnel
- Cost of required instrumentation
- Difficulty of performing tests on different types of components.

Initial efforts concentrated on identifying all the components that make up the HVAC system. This was done by compiling a checklist for every item that was a candidate for inspection. Checklists were developed for the refrigeration process (evaporators, compressors, condensers, chillers), boilers, pumps, chilled and hot water piping systems, steam piping systems, steam traps, heat exchangers, terminal units, fans, and air cleaners. These lists were formulated by interviewing professional mechanical engineers to find out how they ensure HVAC systems are designed and installed correctly, and are operating at maximum efficiency. The purpose of compiling the checklists was to

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[4]Dahtzen Chu, Charles Burton, and Mark Imel.
[5]Dahtzen Chu, Charles Burton, and Mark Imel.

establish a foundation of knowledge on HVAC systems. From this foundation, specific items of information needed by an acceptance test can be extracted. Mechanical contractors were also queried to learn about conventional installation procedures. Design manuals, manufacturers' data, testing and balancing handbooks, and engineering textbooks were researched to obtain in-depth information on different types of systems. These sources are listed in the reference section which accompanies the text of the procedure (see the Appendix). From this foundation work the actual acceptance test procedures were developed.

3 ACCEPTANCE TEST PROCEDURE FOR AIR SUPPLY AND DISTRIBUTION SYSTEMS

The acceptance test procedure described here is intended to cover all types of air supply and distribution systems. It will allow inspectors to systematically measure, analyze, and document several critical energy, flow, pressure, and temperature parameters. They can then use these values to diagnose problems with installation and energy efficiency. The results can be compared with expected values from design calculations and TAB data to ensure the system was installed correctly and is operating efficiently.

To develop the acceptance test procedure, the authors began by determining which components are critical to the energy efficient operation of an air supply and distribution system, e.g., fans. Next, the data that are accurate benchmarks of energy consumption for these components were identified, e.g., air flow and temperature differences. Then standard TAB trade procedures were studied and modified/simplified so that they would measure only these essential data. Existing technology, e.g., conventional TAB instruments, were used throughout the procedure. This approach can make it easier for Corps field inspectors to learn the procedure, since most are somewhat familiar with standard TAB practices. Also Corps field offices may already have conventional TAB instruments or can get access to them.

The complete procedure covers all the major components that could be included in an air supply and distribution system. The procedure is divided into four distinct sections: fans, ducts, coils, and controls. In each section, further subdivisions identify individual component types and their data requirements. Not all these components will be used in an actual facility. The designer or the field office mechanical engineer should tailor the procedure to the particular system to be tested, identifying which types of components are used in the system, and which of them are to be tested. Then the essential measurements and instrumentation can be specified. If spot checking is to be done instead of the complete acceptance test, only applicable sections need to be edited.

All measurements are to be recorded on worksheets included with the procedure. Design values should be supplied by the designer or field office staff, and TAB values should be provided by the field office. Acceptance test data is to be recorded while the personnel perform the test. Some simple calculations will be required for the fans, ducts, and coils sections. No calculations will be needed for the controls section because it is primarily performance-based. It should be possible to perform the full test procedure step-by-step. The text and data forms for the acceptance test are provided in the Appendix. A glossary of potentially unfamiliar acceptance testing terms is included at the end of the procedure.

4 INFORMAL FIELD EVALUATION OF THE ACCEPTANCE TEST PROCEDURE

The authors did an informal field evaluation of the new acceptance test at an Army installation to determine its feasibility. Two battalion headquarters/classroom buildings were selected for the evaluation. One is approximately 12 years old, and the other was just recently constructed. Both have roughly 11,000 to 12,000 sq ft of floor area. Three multizone air handling units are used in the older building while the newer one is served by a single unit. Both buildings are occupied, which constrained the testing somewhat: the air-conditioning systems had to be continuously operated during testing, and no changes to systems settings were permitted. Further difficulties arose because the only easily accessible portions of the air-conditioning systems' ductwork were located in the buildings' mechanical rooms.

The test procedure first calls for an overall review of the system to determine where and how measurements could be made. During the field evaluation, it became apparent that these decisions could cause some problems. Measurements taken at the wrong location can affect the necessary accuracy required for significant calculations. For example, air pressures and velocities should be measured in relatively long, straight sections of ductwork to minimize turbulence in the airstream. The large size of the equipment in the limited space of the buildings' mechanical rooms made it difficult to find ducts long enough to yield proper values for these variables. Because the ceilings were finished and the rooms were occupied, long runs of ductwork outside the mechanical room were not accessible either. Consequently, some readings could have been inaccurate. This problem with insufficient lengths of straight ductwork would not have existed if the evaluation had been done on an uncompleted building in which ceiling tiles had not yet been installed.

On the whole, the procedure is relatively simple, and Corps personnel should be able to use it with ease. The differences in systems in the two buildings did not pose serious difficulties. Airflow measurements were the simplest; the control systems were more difficult to evaluate because of their sophistication. The evaluation found, however, that considerable engineering judgment may be necessary to insure that accurate data is obtained. For instance, measurements collected at the wrong location would produce useless data. Thus, inspectors may need some training in how the procedure operates.

Another finding was that consideration of acceptance testing must begin during the initial design stages. During the informal test of one of the buildings, it was discovered that pressure taps necessary for taking fluid flow measurements were not installed on the piping for the air handling unit. In an actual test situation, this would cause the test results to be incomplete, or delay completion of the test until the taps were installed. If the designers consider the types of tests that will be done during acceptance testing and the components that need to be built into the system to accommodate the tests, problems like this will be prevented. System designs should be standardized with regard to components required for acceptance tests, whenever possible. This will allow the acceptance test procedure to remain consistent from project to project.

Official field tests of the acceptance test procedure will be undertaken in FY88 to evaluate its accuracy and applicability. The procedure will first be performed at a fully monitored control facility to verify its accuracy. Then actual Army facilities will be tested to demonstrate the procedure's applicability and ease of use. The tests include an evaluation of the forms.

5 CONCLUSIONS AND RECOMMENDATIONS

An acceptance test procedure *for air supply and* distribution systems has been developed by interviewing professional mechanical engineers and mechanical contractors and by researching HVAC literature. The procedure uses simple calculations and conventional methods and instruments, and it is intended to be easy for nonexperts to use.

From the preliminary field evaluation, it was concluded that sound engineering judgment must still be used to obtain accurate measurements. Inspectors may need some training to use the procedure. Further, the design of the system affects the ease of using the test.

Short-Range Research Plans

The acceptance test will first be evaluated under controlled conditions to confirm the test's accuracy. The suitability of the data recording forms provided (i.e., format, ease of use, amount of detail) should also be evaluated. The test procedure will be supplemented with photographs and figures, which will make it easier to understand.

Extensive field testing will be undertaken in FY88 at Army facilities, at different geographic locations, and under different climatic conditions. Changes based on the results of these test would make the procedure more adaptable.

Longer-Range Issues

Once the feasibility and practicality of the air supply and distribution acceptance test procedure has been established, it is recommended that other research options be explored. These include:

1. Developing acceptance test procedures for other components of a facility's HVAC system, such as pumps, condensers, or chillers. A system approach to acceptance testing of HVAC systems would then be possible.

2. Automating the data recording and analysis portions of the test using portable computers. This would reduce the amount of time needed to perform the test, and simplify the analysis of the data.

3. Studying electronic and modular testing instrumentation to determine how applicable they are in acceptance testing and which conventional testing instruments they can replace. Modular instrumentation, which can perform different types of tests using interchangeable modules, is available in the commercial market. Other electronic measuring instruments combining increased accuracy with greater ease of use are also becoming available, but at a relatively higher cost. These might reduce the amount of instrumentation, and possibly the amount of time, required to perform acceptance testing. So far, however no research has been done on this equipment to determine its accuracy and ease of use for MCA projects.

4. Performing further research on the use of advanced tracer gas techniques. This technology contains substantial potential for greatly reducing the amount of time necessary to perform acceptance tests for air supply and distribution systems. Some work has already been done for USA-CERL, but much more is needed before these techniques can become both practical and economically feasible.

APPENDIX:

ACCEPTANCE TEST PROCEDURE FOR AIR SUPPLY AND DISTRIBUTION SYSTEMS

This procedure will help determine if air distribution systems in new buildings were installed properly and are operating in an energy efficient manner. Critical energy, flow, pressure, and temperature parameters will be measured. The procedure is presented as an outline, with a section for each category of equipment: fans, ducts, coils, and controls. Each section has a corresponding data worksheet which includes an inspection checklist, and (if applicable) a data section and a calculation section. These forms may be reproduced as necessary for the system to be tested. The data and calculation sections have space where measured data can be compared to design values and to testing, adjusting, and balancing (TAB) results. Any significant discrepancies among these values signal that a closer investigation is needed. The sections are all organized as follows:

A. Exact identification of system being tested. The general category is subdivided as appropriate. This section helps the inspector verify overall compliance with specifications and decide what measurements will be needed. The system should be identified on the first page of the data worksheet.

B. Identification of data required.

   1. Data that will be measured.

   2. Equations that will be used to calculate final efficiency data (items in 1 and 2 are also given on the data and calculation worksheets)

C. Data acquisition methods.

   1. Step-by-step inspection procedures. Visual and functional checks are done first. Results should be recorded on the checklists provided. Then data is measured, calculated, and recorded on the data and calculation worksheets. Specific instructions on measurement methods are not given; standard engineering practice should be used. The procedure can be shortened and simplified by doing only the steps marked with an asterisk (*).

   2. Required equipment (again, listed very generally), and data which must be obtained from manufacturers' information.

CONTENTS

I. FANS

A. Type of Fan:

1. Centrifugal

   a. Forward Curved
   b. Backward Inclined
   c. Air-Foil
   d. Tubular Centrifugal

2. Axial

   a. Propeller
   b. Tubeaxial
   c. Vaneaxial

B. Identification of Data Required:

1. Data Required:

   a. Volumetric Air Flow
   b. Differential Pressure
   c. Motor Speed
   d. Electrical Power

2. Use of Data:

   a. $AHP_s = (cfm * P_s)/6356$

   b. $AHP_t = (cfm * P_t)/6356$

   c. Static Efficiency = AHP_s/BHP_a

   d. Total Efficiency = AHP_t/BHP_a

   where: AHP_s = static air horsepower
   AHP_t = total air horsepower
   BHP_a = approximate brake horsepower
   cfm = flow rate at diffuser
   P_t = total airstream pressure
   P_s = static airstream pressure
   * = multiply
   / = divide

   Note: Use the following formula to determine approximate BHP_a

$$\text{Corrected Full Load Amps (CFLA)} = \frac{A_{np} * V_{np}}{V_{fc}}$$

$$\text{Approximate } BHP_a = HP_{np} * \frac{\text{Motor Operating Amps}}{\text{CFLA}}$$

where: A_{np} = nameplate amps

HP_{np} = nameplate horsepower

V_{fc} = field checked voltage

V^{np} = nameplate voltage

C. Data Acquisition Procedures:

1. Methods:

a. Verify the equipment matches the TAB report for nameplate data such as model number, make, arrangement, class, etc.

b. Verify all parts are functioning properly.

c. Locate all start-stop disconnect switches, electrical interlocks, and motor starters. Motors must be equipped with thermal overload protection of the proper size.

d. Check availability of electrical power to all equipment and verify the compatibility of voltage and phase. The average voltage delivered to the motor should not vary more than a few volts from the nameplate rating.

Note: 1. Single-phase motors: Place voltmeter clamp around one wire and connect leads to the starter's two load terminals. The reading will show the voltage of the current being applied to the motor.

2. Three-phase motors: Connect the voltmeter terminals to poles no. 1 and 2 first, then to poles no. 2 and 3, then to poles no. 3 and 1. Take the average of the three readings.

e. Inspect the inlet and discharge of fan plenums for obstructions. Plenum and ductwork failure or collapse can result from closed dampers.

f. Confirm air filter size, type, number, and condition. If high efficiency filters are used, check to see that the filter frames are sealed to the plenum or duct to prevent leakage.

* g. By using a tachometer, confirm fan motor rpm is set as designed, and record on System Data Section of the Fan Data Worksheet.

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*Note: For simplest method, perform only steps g, h, i, and j.

* h. Perform necessary airflow measurements using duct traverse worksheet and record on System Data Section of the Fan Data Worksheet.

* i. Verify amperes and horsepower by using a voltmeter. The power factor must be verified to determine exact kilowatt consumption.

* j. Do the calculations specified under "Use of Data" and record the results in the Calculations section of the Fan Data Worksheet.

2. Equipment and Data Required: (see attached glossary)

   a. Pitot Tube - used in conjunction with manometer to measure volumetric air flow and airstream pressure (see Figure A1 for proper connections)

   b. Manometer

   c. Voltmeter - to measure electric voltages and currents

   d. Tachometer - to measure fan motor speed

   e. Manufacturer's fan performance curve - to measure efficiency of fan.

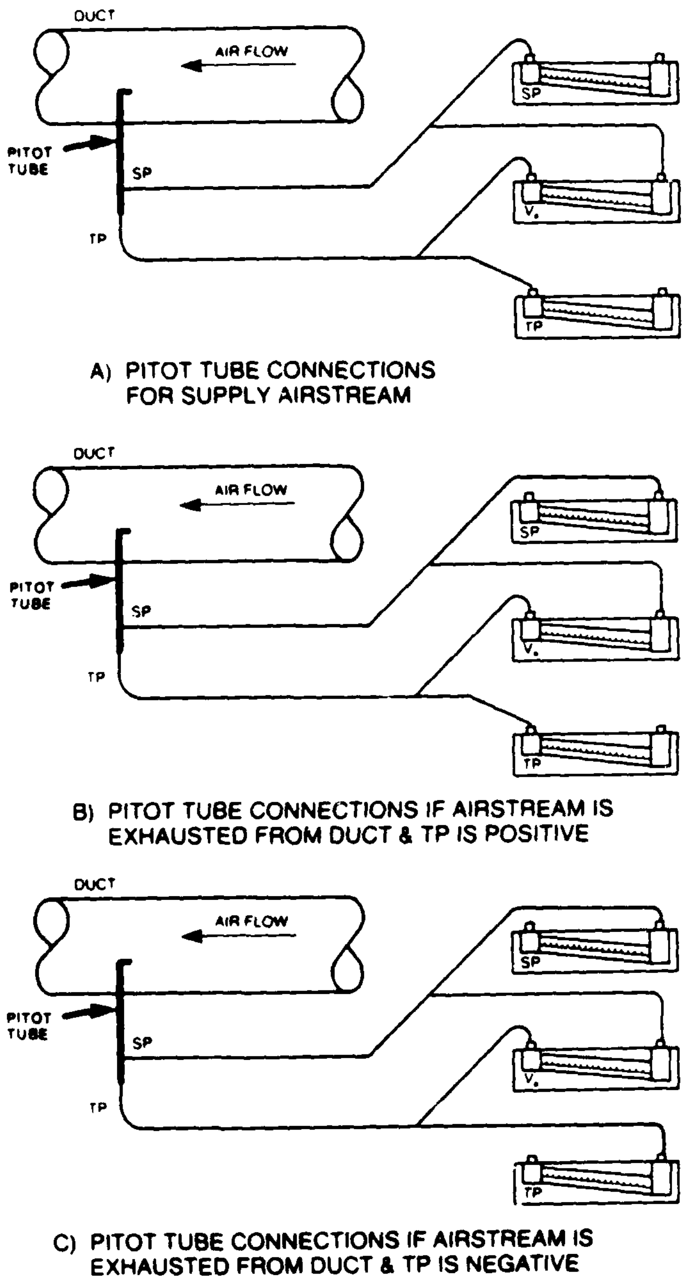


Figure A1. Pitot tube connections to a manometer for measuring static air pressure (SP), velocity pressure (VP), or total air pressure (TD) for various airstream designs. Source: *Procedural Standards for Testing, Adjusting, Balancing of Environmental Systems* (National Environmental Balancing Bureau, 1983), p 2.5.

FAN DATA WORKSHEET

PROJECT: ______________________________

EQUIPMENT LOCATION: ______________________________

FAN TYPE: ______________________________ ____________

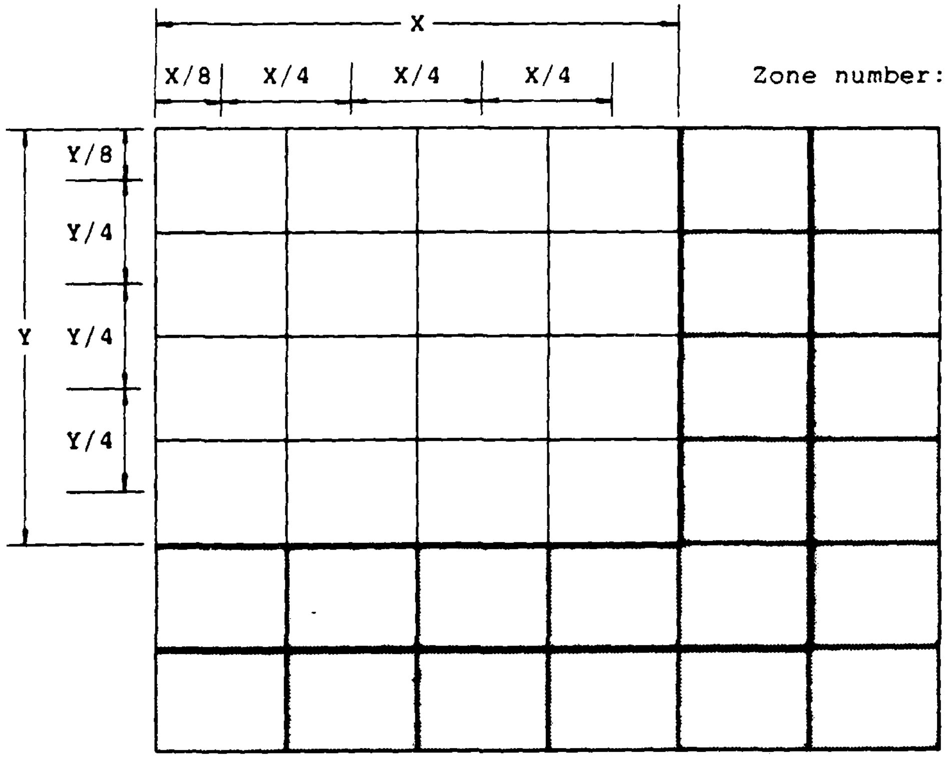
SYSTEM CHECKS:

	Ready yes	no	Date checked
1. Nameplate data			
2. Rotation (in correct direction)			
3. Wheel clearance and balance			
4. Bearing and motor lubrication			
5. Drive alignment and belt tension			
6. Drive set screws tight			
7. Belt guard in place			
8. Flexible duct connector alignment			
9. Starters and disconnect switches			
10. Electrical service and connections			
11. Fan inlet and discharge			
12. Air filters			

DUCT TRAVERSE WORKSHEET:

Use this worksheet to calculate volumetric airflow at fan outlet or zone. Divide duct to be measured into 16 blocks. Use manometer and pitot tube to take readings of velocity pressure at the centerpoint of each block. Convert velocity pressure to velocity using attached table, and mark down in the appropriate space below.

Zone number: ______



Note: If the maximum distance between traverse points is greater than 6", expand the duct traverse diagram as necessary by using the shaded blocks of the diagram.

$$\text{Average Velocity (fpm)} = \frac{\text{Sum of Readings}}{\text{Number of Readings}} =$$

$$\text{Net Area } (ft^2) = \frac{(\text{Duct Width}) * (\text{Duct Height})}{144} =$$

Volumetric Air Flow (cfm) = (Average Velocity) * (Net Area)

Average Velocity *	Net Area =	Volumetric Air Flow

$V = 4005\sqrt{VP}$ Velocity in feet per minute and velocity pressure in inches of water

VP	V	VP	V	VP	V	VP	V	VP	V	VP	V	VP	V	VP	V
.001	127	.085	1167	.169	1646	.253	2015	.337	2325	.70	3351	1.54	4970	2.38	6179
.002	179	.086	1175	.170	1651	.254	2019	.338	2329	.71	3375	1.55	4986	2.39	6191
.003	219	.087	1181	.171	1656	.255	2023	.339	2332	.72	3398	1.56	5002	2.40	6204
.004	253	.088	1188	.172	1661	.256	2027	.340	2335	.73	3422	1.57	5018	2.41	6217
.005	283	.089	1193	.173	1666	.257	2031	.341	2338	.74	3445	1.58	5034	2.42	6230
.006	310	.090	1201	.174	1670	.258	2035	.342	2342	.75	3468	1.59	5050	2.43	6243
.007	335	.091	1208	.175	1675	.259	2039	.343	2345	.76	3491	1.60	5066	2.44	6256
.008	358	.092	1215	.176	1680	.260	2042	.344	2349	.77	3514	1.61	5082	2.45	6269
.009	380	.093	1222	.177	1685	.261	2046	.345	2352	.78	3537	1.62	5098	2.46	6281
.010	400	.094	1228	.178	1690	.262	2050	.346	2356	.79	3560	1.63	5114	2.47	6294
.011	420	.095	1234	.179	1695	.263	2054	.347	2360	.80	3582	1.64	5129	2.48	6307
.012	439	.096	1241	.180	1699	.264	2058	.348	2363	.81	3604	1.65	5144	2.49	6319
.013	457	.097	1247	.181	1704	.265	2062	.349	2366	.82	3625	1.66	5160	2.50	6332
.014	474	.098	1254	.182	1709	.266	2066	.350	2369	.83	3657	1.67	5175	2.51	6345
.015	491	.099	1260	.183	1713	.267	2070	.351	2372	.84	3669	1.68	5191	2.52	6358
.016	507	.100	1266	.184	1718	.268	2074	.352	2376	.85	3690	1.69	5206	2.53	6370
.017	522	.101	1273	.185	1723	.269	2078	.353	2379	.86	3709	1.70	5222	2.54	6383
.018	537	.102	1279	.186	1727	.270	2081	.354	2383	.87	3729	1.71	5237	2.55	6395
.019	552	.103	1285	.187	1732	.271	2085	.355	2386	.88	3758	1.72	5253	2.56	6408
.020	566	.104	1292	.188	1737	.272	2089	.356	2389	.89	3779	1.73	5268	2.57	6420
.021	580	.105	1298	.189	1741	.273	2093	.357	2393	.90	3800	1.74	5283	2.58	6433
.022	594	.106	1304	.190	1746	.274	2097	.358	2396	.91	3821	1.75	5298	2.59	6445
.023	607	.107	1310	.191	1750	.275	2101	.359	2400	.92	3842	1.76	5313	2.60	6458
.024	620	.108	1316	.192	1755	.276	2105	.360	2403	.93	3863	1.77	5328	2.61	6470
.025	633	.109	1322	.193	1759	.277	2119	.361	2406	.94	3884	1.78	5343	2.62	6482
.026	645	.110	1328	.194	1764	.278	2113	.362	2410	.95	3904	1.79	5359	2.63	6495
.027	658	.111	1334	.195	1768	.279	2116	.363	2413	.96	3924	1.80	5374	2.64	6507
.028	670	.112	1340	.196	1773	.280	2119	.364	2416	.97	3945	1.81	5388	2.65	6519
.029	682	.113	1346	.197	1777	.281	2123	.365	2420	.98	3965	1.82	5403	2.66	6532
.030	694	.114	1352	.198	1782	.282	2127	.366	2423	.99	3985	1.83	5418	2.67	6544
.031	705	.115	1358	.199	1787	.283	2131	.367	2426	1.00	4005	1.84	5433	2.68	6556
.032	716	.116	1364	.200	1791	.284	2135	.368	2429	1.01	4025	1.85	5447	2.69	6569
.033	727	.117	1370	.201	1795	.285	2139	.369	2433	1.02	4045	1.86	5462	2.70	6581
.034	738	.118	1375	.202	1800	.286	2143	.370	2436	1.03	4064	1.87	5477	2.71	6593
.035	749	.119	1382	.203	1804	.287	2147	.371	2439	1.04	4084	1.88	5491	2.72	6605
.036	759	.120	1387	.204	1809	.288	2151	.372	2443	1.05	4103	1.89	5506	2.73	6617
.037	770	.121	1393	.205	1813	.289	2154	.373	2445	1.06	4123	1.90	5521	2.74	6629
.038	780	.122	1399	.206	1818	.290	2157	.374	2449	1.07	4142	1.91	5535	2.75	6641
.039	791	.123	1404	.207	1822	.291	2161	.375	2453	1.08	4162	1.92	5550	2.76	6654
.040	801	.124	1410	.208	1827	.292	2164	.376	2456	1.09	4181	1.93	5564	2.77	6666
.041	811	.125	1416	.209	1831	.293	2168	.377	2459	1.10	4200	1.94	5579	2.78	6678
.042	821	.126	1422	.210	1835	.294	2171	.378	2462	1.11	4219	1.95	5593	2.79	6690
.043	831	.127	1427	.211	1839	.295	2175	.379	2466	1.12	4238	1.96	5608	2.80	6702
.044	840	.128	1433	.212	1844	.296	2179	.380	2469	1.13	4257	1.97	5623	2.81	6714
.045	849	.129	1439	.213	1848	.297	2182	.381	2472	1.14	4276	1.98	5637	2.82	6725
.046	859	.130	1444	.214	1853	.298	2186	.382	2475	1.15	4295	1.99	5651	2.83	6737
.047	868	.131	1449	.215	1857	.299	2189	.383	2479	1.16	4314	2.00	5664	2.84	6749
.048	877	.132	1455	.216	1862	.300	2193	.384	2481	1.17	4332	2.01	5678	2.85	6761
.049	887	.133	1461	.217	1866	.301	2197	.385	2485	1.18	4350	2.02	5692	2.86	6773
.050	896	.134	1466	.218	1870	.302	2200	.386	2488	1.19	4368	2.03	5706	2.87	6785
.051	904	.135	1471	.219	1875	.303	2204	.387	2491	1.20	4386	2.04	5720	2.88	6797
.052	913	.136	1477	.220	1879	.304	2208	.388	2495	1.21	4405	2.05	5734	2.89	6809
.053	922	.137	1482	.221	1883	.305	2212	.389	2499	1.22	4423	2.06	5748	2.90	6820
.054	931	.138	1488	.222	1887	.306	2215	.390	2501	1.23	4442	2.07	5762	2.91	6832
.055	939	.139	1493	.223	1892	.307	2219	.40	2533	1.24	4460	2.08	5776	2.92	6844
.056	948	.140	1498	.224	1896	.308	2223	.41	2563	1.25	4478	2.09	5790	2.93	6855
.057	956	.141	1504	.225	1900	.309	2226	.42	2595	1.26	4495	2.10	5804	2.94	6867
.058	964	.142	1509	.226	1905	.310	2230	.43	2626	1.27	4513	2.11	5817	2.95	6879
.059	973	.143	1515	.227	1909	.311	2233	.44	2656	1.28	4531	2.12	5831	2.96	6890
.060	981	.144	1520	.228	1913	.312	2236	.45	2687	1.29	4549	2.13	5845	2.97	6902
.061	989	.145	1525	.229	1917	.313	2239	.46	2716	1.30	4566	2.14	5859	2.98	6913
.062	996	.146	1530	.230	1921	.314	2242	.47	2746	1.31	4583	2.15	5872	2.99	6925
.063	1004	.147	1536	.231	1925	.315	2245	.48	2775	1.32	4601	2.16	5886	3.00	6937
.064	1012	.148	1541	.232	1929	.316	2248	.49	2804	1.33	4619	2.17	5899	3.01	6948
.065	1020	.149	1546	.233	1933	.317	2251	.50	2832	1.34	4636	2.18	5913	3.02	6960
.066	1029	.150	1551	.234	1937	.318	2254	.51	2860	1.35	4653	2.19	5927	3.03	6971
.067	1037	.151	1556	.235	1941	.319	2257	.52	2888	1.36	4671	2.20	5940	3.04	6983
.068	1045	.152	1561	.236	1945	.320	2260	.53	2916	1.37	4688	2.21	5954	3.05	6994
.069	1052	.153	1567	.237	1950	.321	2264	.54	2943	1.38	4705	2.22	5967	3.06	7006
.070	1060	.154	1572	.238	1954	.322	2268	.55	2970	1.39	4722	2.23	5981	3.07	7017
.071	1067	.155	1577	.239	1958	.323	2272	.56	2997	1.40	4739	2.24	5994	3.08	7028
.072	1075	.156	1582	.240	1962	.324	2276	.57	3024	1.41	4756	2.25	6008	3.09	7040
.073	1082	.157	1587	.241	1966	.325	2280	.58	3050	1.42	4773	2.26	6021	3.10	7051
.074	1089	.158	1592	.242	1970	.326	2284	.59	3076	1.43	4790	2.27	6034	3.11	7063
.075	1097	.159	1597	.243	1974	.327	2289	.60	3102	1.44	4806	2.28	6047	3.12	7074
.076	1104	.160	1602	.244	1978	.328	2293	.61	3127	1.45	4823	2.29	6060	3.13	7085
.077	1111	.161	1607	.245	1982	.329	2297	.62	3153	1.46	4840	2.30	6074	3.14	7097
.078	1119	.162	1612	.246	1987	.330	2301	.63	3179	1.47	4856	2.31	6087	3.15	7108
.079	1125	.163	1617	.247	1991	.331	2304	.64	3204	1.48	4873	2.32	6100	3.16	7119
.080	1133	.164	1622	.248	1995	.332	2308	.65	3229	1.49	4889	2.33	6113	3.17	7131
.081	1140	.165	1627	.249	1999	.333	2311	.66	3254	1.50	4905	2.34	6126	3.18	7142
.082	1147	.166	1632	.250	2003	.334	2315	.67	3279	1.51	4921	2.35	6139	3.19	7153
.083	1154	.167	1637	.251	2007	.335	2318	.68	3303	1.52	4938	2.36	6152	3.20	7164
.084	1161	.168	1642	.252	2011	.336	2322	.69	3327	1.53	4954	2.37	6165		

VELOCITY FOR VARIOUS VELOCITY PRESSURES

(Source: TAB Services, Ltd., Altoona WI; used with permission.)

FAN SYSTEM DATA:

		Design	TAB	Actual
Fan Motor Nameplate Amps	A_{np}			
Fan Motor Nameplate Voltage	V_{np}			
Fan Motor Nameplate Horsepower	HP_{np}			
Fan Motor Operating Amps	A_{op}			
Fan Motor Field Checked Voltage	V_{fc}			
Fan Motor rpm	rpm			
Fan rpm	rpm			
Volumetric Air Flow (cfm)	cfm			
Total Airstream Pressure (P_t)	in. wg			
Static Airstream Pressure (P_s) in. wg	inlet			
	discharge			

FAN CALCULATIONS:

		Design	TAB	Actual
Corrected Full Load Amps (CFLA) CFLA = $(A_{np} * V_{np})/V_{fc}$				
Approximate Brake Horsepower (BHP_a) $BHP_a = A_{op}/CFLA$	HP			
Total Air Horsepower (AHP_t) $AHP_t = (cfm * P_t)/6356$	HP			
Static Air Horsepower (AHP_s) $AHP_s = (cfm * P_s)/6356$	HP			
Static Efficiency = AHP_s/BHP_a	%			
Total Efficiency = AHP_t/BHP_a	%			

Note: Use results of calculations to plot a point on the performance curve (provided by the manufacturer) that the fan is operating at. This should determine if the fan is operating at an acceptable efficiency or not (acceptability ranges should also be provided by the manufacturer.)

RECOMMENDED ACTIONS:____

THIS SPACE FOR CALCULATIONS:

II. DUCTS

A. Identification of System to be Tested:

1. Type of Duct:

a. Velocity

1) Low Velocity - up to 2500 fpm
2) High Velocity - above 2500 fpm

b. Pressure

1) Low Pressure - up to 3 3/4 in. wg
2) Medium Pressure - 3 3/4 to 6 3/4 in. wg
3) High Pressure - 6 3/4 to 12 1/4 in. wg

Note: These pressure ranges are total pressures, including the losses through the air handling apparatus, (filter, coils, and casing) ductwork, and the air terminal in the space.

B. Identification of Data Required:

1. Data Required:

a. Volumetric Airflow at Zone Inlet (cfm)
b. Volumetric Airflow at Diffusers (cfm)
c. Air Temperature at Zone Inlet (T_z)
d. Air Temperature at Diffusers (T_d)

2. Use of Data

a. Airflow Efficiency =

$$\frac{\text{Total Volumetric Airflow for Zone's Diffusers}}{\text{Volumetric Airflow at Zone Inlet}} \times 100\%$$

Note: If the Air Flow Efficiency is less than 90 percent, duct leakage or blockage should be located and corrected.

b. Air Temperature Difference = $T_d - T_z$

Note: This is calculated for each diffuser. If the Air Temperature Difference is more than 10 percent of the zone inlet temperature, the source of heat loss or heat gain must be determined and corrected.

C. Data Acquisition Procedures:

1. Methods:

* a. Check that all outside air intake, return and exhaust air dampers are in the proper position and/or operational.

b. Check that all system volume dampers and fire dampers have been installed, are in full open position, and are accessible.

c. Inspect access doors and hardware for tightness and leakage and verify that all necessary access doors have been installed.

* d. Verify that all air terminals and terminal units have been installed and that terminal dampers are fully open.

e. Inspect duct systems for proper construction, that all turning vanes have been installed, and that all joints have been sealed as specified.

f. Inspect coils, duct heaters, and terminals for leakage at duct connections and piping penetrations.

g. Confirm that openings have been provided in walls and plenums for proper air passage.

h. Confirm that all architectural features such doors, ceiling plenums, and windows are installed and are functional with regard to airflow of the duct systems being tested.

* i. Confirm locations for pitot tube traverse measurements and accessibility for testing measurements in general.

* j. Perform necessary airflow and temperature measurements and calculations and record on Duct Data Worksheet (use the duct traverse worksheet for airflow).

2. Equipment Required: (see attached glossary)

   a. Pitot tube - used in conjunction with manometer to measure volumetric airflow

   b. Manometer

   c. Flow Hood - to measure volumetric air flow at individual diffusers

   d. Thermometer - to measure air temperature.

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*Note: For simplest method, perform only steps a, d, i, and j.

DUCT DATA WORKSHEET

PROJECT: ____________________

DUCT TYPE: (low)(high) Velocity (low)(medium)(high) Pressure

SYSTEM CHECKS:

	Ready yes	no	Date checked
1. Outside air intake, return, and exhaust air dampers in proper position			
2. System volume dampers and fire dampers open and accessible			
3. Access doors closed and tight			
4. Terminal units, registers, and diffusers fully open and set			
5. Turning vanes in square elbows			
6. Ductwork sealed as required			
7. Coils, duct heaters, terminals inspected for leakage			
8. Air shafts and openings as required			
9. Windows and doors installed and closed			
10. Ceiling plenums installed and sealed			

DUCT SYSTEM DATA:

Zone No.	Design		TAB		Actual	
	Airflow cfm	Temp T_z	Airflow cfm	Temp T_z	Airflow* cfm	Temp T_z
Diffuser No.	cfm	T_d	cfm	T_d	cfm	T_d
Total cfm						

*Use duct traverse worksheet (Fan Data, page 2) to calculate airflow.

DUCT CALCULATIONS:

$$\text{Airflow Efficiency (AFE)} = \frac{\text{Total Volumetric Airflow for Diffusers}}{\text{Volumetric Airflow at Zone Inlet}} * 100\ \%$$

	Design	TAB	Actual
AFE			

Note: If airflow efficiency is less than 90%, duct leakage or blockage should be located.

Air Temperature Difference = $T_d - T_z$

where: T_d = Air Temperature at Diffuser
T_z = Air Temperature at Zone Inlet

Diffuser Number										
$T_d - T_z$										

Note: This is calculated for each diffuser. If the Air Temperature Difference is more than 10 percent of the Zone Inlet Air Temperature, the source of heat loss or heat gain must be determined and corrected.

RECOMMENDED ACTIONS: ______________________________

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THIS SPACE FOR CALCULATIONS:

III. COILS

A. Type of Coils:

1. Chilled Water
2. Direct Expansion
3. Hot Water

B. Identification of Data Required:

1. Data Required:

a. Flow Rate of Fluid
b. Flow Rate of Air
c. Air Entering and Leaving Temperatures
d. Fluid Entering and Leaving Temperatures
e. Entering and Leaving Humidity Ratio
f. Water Pressure Drop
g. Air Pressure Drop

2. Use of Data:

a. Air:

1. $Q_s = 1.08 * cfm * \Delta T_{db}$
2. $Q_l = 0.7 * cfm * \Delta g$
3. $Q_t = Q_s + Q_l$

b. Water:

1. $Q_{water} = 500 * gpm * \Delta T_{water}$
2. $EFF_{tot} = Q_t / Q_{water}$ (cooling)
3. $EFF_{tot} = Q_s / Q_{water}$ (heating)

c. Direct Expansion:

1. $EFF_{tot} = Q_t / Q_{coil}$

where:
Q_s = sensible heat
Q_l = latent heat
Q_t = total heat
cfm = air flow rate at coil inlet
ΔT_{db} = change in dry bulb temperature
Δg = change in the humidity ratio (in grains of moisture per pound of dry air)

Q_{water} = heat transfer (water)
gpm = fluid flow rate through coil
ΔT_{water} = change in water temperature
EFF_{tot} = total coil efficiency
Q_{coil} = coil heat transfer
* = multiply
/ = divide

Note: For each coil, measure the entering and leaving air dry bulb and wet bulb temperatures. Plot the air temperatures on a psychrometric chart and find the change in humidity ratio (Δg). (See Figure A2.)

C. Data Acquisition Procedures:

1. Methods:

* a. Verify size and physical data.

  b. Inspect for coil obstructions and/or debris and leakage in piping.

  c. Verify proper piping methods, connections for flow, pipe sizes, venting devices, etc.

  d. Verify air flow directions.

* e. Check to see that coil is placed in proper direction.

  f. Confirm operation of control valve.

* g. Confirm operation, type, and size of automatic valve, expansion valves, and other control equipment.

* h. Perform necessary measurement procedures and calculations and record on Coil Data Worksheet. (Use duct transverse worksheet in Fan Data Worksheet to calculate airflow.)

2. Equipment and Data Required: (See attached glossary)

  a. Pitot Tube - used in conjunction with manometer to measure airstream pressure

  b. Manometer

  c. Differential Pressure Gauge - to measure fluid flow pressure drop

  d. Portable Electronic Temperature Measurement Device

  e. Manufacturer's data for direct expansion coil (if required).

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*Note: For simplest method, perform only steps a, e, g, and h.

PSYCHROMETRIC CHART PLOTTING EXAMPLE

SENSIBLE HEAT = CFM * 1.08 *Δ T(db)

SENSIBLE HEAT = ____* 1.08 *______=______

LATENT HEAT = CFM * 0.70 *Δ g

LATENT HEAT = ____* 0.70 *__ __=______

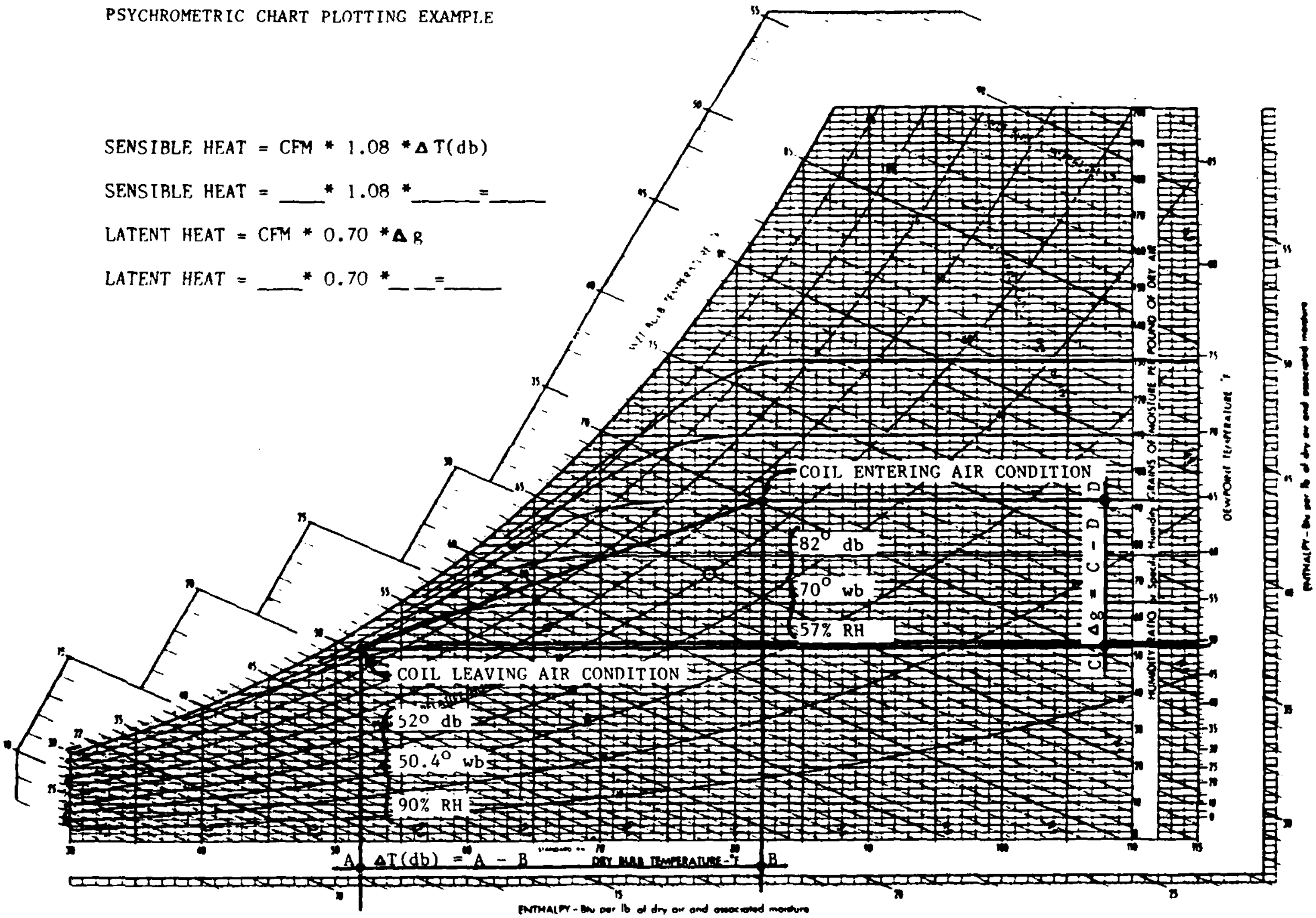

Figure A2. Psychrometric chart plotting example. Source: © The Trane Company Division of American Standard, Inc., 1960. Reprinted with permission.

COIL DATA WORKSHEET

PROJECT: ______________________________

COIL TYPE: ______________________________

SYSTEM CHECKS:

	Ready yes	no	Date checked
1. Size and rows			
2. Fin spacing and condition			
3. Obstructions and/or debris			
4. Piping leakage			
5. Correct piping connections and flow			
6. Air vents			
7. Airflow and direction			
8. Coil placed in proper direction			
9. Valves open or set			

PUMP SYSTEM DATA:

		Design	TAB	Actual
Pump Motor Nameplate Amps	A_{pnp}			
Pump Motor Nameplate Voltage	V_{pnp}			
Pump Motor Nameplate Horsepower	HP_{pnp}			
Pump Motor Operating Amps	A_{pop}			
Pump Motor Field Checked Voltage	V_{pfc}			
Pump Motor rpm	rpm			
Total System Pressure Drop (measured at pump)	ft hd			

COIL SYSTEM DATA:

Air Measurements:		Design	TAB	Actual
Airflow rate (cfm)	cfm			
Entering dry bulb temp (T_{endb})	deg F			
Entering wet bulb temp (T_{enwb})	deg F			
From psychrometric chart: Entering humidity ratio (HR_{en})	g/lbm			
Entering pressure (P_{en})	in wg			
Leaving dry bulb temp (T_{lvdb})	deg F			
Leaving wet bulb temp (T_{lvwb})	deg F			
From psychrometric chart: Leaving humidity ratio (HR_{lv})	g/lbm			
Leaving pressure (P_{lv})	in wg			
Change in dry bulb temp (ΔT_{db}) $\Delta T_{db} = T_{endb} - T_{lvdb}$ (cooling) $\Delta T_{db} = T_{lvdb} - T_{endb}$ (heating)	deg F			
Change in humidity ratio (Δg) $\Delta g = HR_{en} - HR_{lv}$	g/lbm			
Pressure drop (PD_{air}) $PD_{air} = P_{en} - P_{lv}$	in wg			

Water Measurements:		Design	TAB	Actual
Water flow rate (gpm)	gpm			
Entering temperature (EWT)	deg F			
Entering pressure (EWP)	in wg			
Leaving temperature (LWT)	deg F			
Leaving pressure (LWP)	in wg			
Change in water temp (ΔT_{water}) ΔT_{water} = EWT - LWT (cooling) ΔT_{water} = LWT - EWT (heating)	deg F			
Pressure drop (PD_{water}) PD_{water} = EWP - LWP	in wg			

COIL CALCULATIONS:

Air:	Design	TAB	Actual
Sensible Heat (Q_s) BtuH $Q_s = 1.08 * cfm * \Delta T_{db}$			
If testing for cooling conditions, also calculate the following:			
Latent Heat (Q_l) BtuH $Q_l = 0.7 * cfm * \Delta g$			
Total Heat (Q_t) BtuH $Q_t = Q_s + Q_l$			

For Water (liquid) Coils:	Design	TAB	Actual
Heat Transfer (Q_{water}) $Q_{water} = 500 * gpm * \Delta T_{water}$ BtuH			
Total Coil Efficiency (EFF_{tot}) % $EFF_{tot} = Q_t / Q_{water}$ (cooling) $EFF_{tot} = Q_s / Q_{water}$ (heating)			

For Direct Expansion Coils:	Design	TAB	Actual
Coil Heat Transfer (Q_{coil}) BtuH per manufacturer			
Total Coil Efficiency (EFF_{tot}) % $EFF_{tot} = Q_t / Q_{coil}$			

RECOMMENDED ACTIONS: ____

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THIS SPACE FOR CALCULATIONS:

IV. CONTROLS

A. Control System Components

1. Sensing Elements

    a. Temperature

        1) Bimetal
        2) Rod-and-Tube
        3) Sealed Bellows
        4) Remote Bulb
        5) Resistance

    b. Humidity

        1) Hygroscopic
        2) Electrical

    c. Pressure

2. Controllers

    a. Electric/Electronic

        1) Two-Position
        2) Floating Control
        3) Proportional

    b. Pneumatic

        1) Nonrelay
        2) Relay
        3) Direct Acting
        4) Reverse Acting

3. Thermostats

    a. Day-Night
    b. Heating-Cooling
    c. Multistage
    d. Submaster
    e. Wet-Bulb
    f. Dew Point

4. Transducers

    a. PE (Pneumatic to Electric)
    b. EP (Electric to Pneumatic)
    c. Modulating (A device that will change a modulating air signal to a variable voltage output, or a variable electric or electronic signal may produce a varying air pressure output.)

5. Control Devices

a. Automatic Valves

1) Single-seated
2) Pilot Piston
3) Double-seated or Balanced
4) Three-way Mixing
5) Three-way Diverting
6) Butterfly

b. Valve Operators

1) Solenoid
2) Electric Motor

a) Unidirectional
b) Spring Return
c) Reversible

3) Pneumatic

c. Automatic Dampers

1) Single-blade
2) Multi-blade

a) Parallel Operation
b) Opposed Operation

3) Mixing

d. Damper Operators (similar to valve operators)

1) Electric

a) Unidirectional
b) Spring Return
c) Reversible

2) Pneumatic

B. Data Acquisition Procedures:

1. Methods:

a. Review specifications to determine proper control schedules.

b. Verify that the controllers are properly installed in the specified location (see contract drawings).

c. Verify that the sensing elements are properly installed in the specified location (see contract drawings).

d. Confirm connection between sensing element and appropriate controller (see temperature control shop drawing).

e. Verify connection between the controller and relays and/or actuators that operate the dampers and valves.

f. Confirm that pneumatic lines are either soft copper or nylon reinforced tubing with branch piping commonly 1/4 in. to 1/8 in. pipe size.

g. Confirm appropriate corrective action of the controller due to a deviation between the controlled variable and the controller set point.

h. Verify that dampers and valves are in the proper position (NO = normally open; NC = normally closed) and operational.

i. Verify the proper operating air pressure for the pneumatic control system. The pressure usually ranges 3 to 20 psig depending on the device, although higher pressures are occasionally used for operating very large valves and dampers.

j. Verify that the compressed air supply dryer is operational and that the filter is free from oil and dirt.

k. Verify proper operating voltage for electric/electronic systems. Electrical systems are commonly line voltage of 120/240 V or low voltage typically 24 V. Electronic systems are commonly 5 V with a 15 V maximum (see shop drawings).

l. Confirm proper location and installation of safety controls such as high temperature sensors, low temperature sensors, and smoke detectors.

m. Check that all pneumatic lines, electrical wires, and devices are properly supported and protected against damage.

n. Confirm the change in pneumatic supply air pressure from day/night or summer/winter use.

CONTROLS DATA WORKSHEET

PROJECT: ____________________

CONTROLS LOCATION: ____________________

CONTROLS TYPE: ____________________

SYSTEM CHECKS:

	Ready yes	no	Date checked
1. Controllers installation and location			
2. Sensing elements installation and location			
3. Controller set point			
4. Connections between sensing elements, controllers, and controlled devices			
5. Dampers and valves			
6. Pneumatic operating air pressure			
7. Air dryer and filter			
8. Electric/electronic operating voltages			
9. Safety controls installation and location			
10. Pneumatic lines, electric wires and devices			
11. Change in pneumatic supply air pressure (day/night, summer/winter)			

RECOMMENDED ACTIONS: ____________________

V. ACCEPTANCE TESTING GLOSSARY

Automatic Dampers:

Mixing: A damper composed of two damper sections interlinked so that one section opens as the other one closes.

Multiblade: This damper has two or more blades linked together.

a. Opposed Operation: Adjacent blades rotate in opposite direction.

b. Parallel Operation: All the blades rotate in the same direction.

Automatic Valves:

Butterfly: This valve consists of a heavy ring enclosing a disc which rotates on an axis.

Double-seated or Balanced: This valve is designed so that the media pressure acting against the valve disc is essentially balanced, reducing the force required of the valve operator.

Pilot Piston: The pressure of the control agent is used as an aid in operating the valve.

Three-way Diverting: This valve has one inlet and two outlet connections, and two separate discs and seats. It is used to divert the flow to either of the outlets, or to proportion the flow to both outlets.

Three-way Mixing: This valve has two inlet and one outlet connection, and a double-faced disc operating between two seats. This valve is used to mix two fluid streams.

Brake Horsepower: The actual horsepower required to drive the fan. It is greater than a theoretical "air horsepower" because it includes loss due to turbulence and other inefficiencies in the fan, plus bearing losses.

Coils: Coils are used for heating and cooling an air stream under forced convection. This may consist of a single coil section or a number of individual coil sections built up into banks. Coils are also used as components in central station type air handling units, room terminals, and in factory-assembled, self-contained air-conditioners. The usual media used in extended surface coils are chilled water or volatile refrigerants.

Coil Efficiency: The ratio of the heat output or the heat removed by the coil in BTUh (British Thermal Units per hour) to the total capacity of the coil in BTUh.

Control Agent: The medium such as air, gas, water, or electrical current, being manipulated by a control device.

Control Device: A device that reacts to the signal received from a controller, and varies the flow of the Control Agent.

Controller: A device that takes the sensing element output, compares it with the desired control condition, and regulates an output signal to cause various types of control action.

Controls: HVAC control systems alter the system variables in a prescribed manner so that the heating, cooling, and humidifying equipment capacities are changed to meet the building, equipment, and occupant loads. They can also control the relative pressure between two spaces, and act as safety controls that prevent equipment from operating when it is unsafe.

Damper Operators: Similar to valve operators. See definition below.

Dew Point Temperature: The temperature at which moisture would begin to condense out of the air if the air should be cooled to that temperature.

Differential Pressure: See Pressure Drop.

Differential Pressure Gauge: A dual inlet, Bourdon tube pressure gauge with a dial pointer that indicates the differential pressure existing between two measured pressures. The gauge is used to measure hydronic flow pressure drop.

Duct: Ductwork is used to transmit air from air handling apparatus to the space to be conditioned.

Duct Pressure: The normal force exerted by the air, per unit of area, on the wall of the duct.

Duct Velocity: The time rate and direction of airflow through the duct.

Electric/Electronic Controllers:

Floating Control: The controller output is a single-pole, double-throw switching circuit with a neutral zone where neither contact is made.

Proportional: The controller gives continuous or incremental changes in the output signal to position an electrical actuator.

Two-Position: The controller output may be a simple electrical contact that activates a control device.

Fan: The fan is the "pump" or prime mover of an air handling system which creates pressure differences that cause air to flow through the system.

Fan Efficiency: The ratio of the fan output in horsepower to the total power input in horsepower.

Fan Performance Curve: This is a constant speed performance curve. It is a graphical presentation of static or total pressure and power input over a range of air volume flow rate at a stated inlet density and fan speed. It may include static and mechanical efficiency curves. The range of air volume flow rate which is covered generally extends from shutoff (zero air volume flow rate) to free delivery (zero fan static pressure).

Flow Hood: A conical or pyramid-shaped hood equipped with instruments to measure airstream cfm flow at air terminals.

Humidity Sensing Elements:

Electrical: A humidity change will cause a change in resistance or capacitance due to the hygroscopic nature of the element.

Hygroscopic: An organic material such as wood, paper, or hair that changes in size or form with a change in humidity, causing a mechanical deflection.

Hygroscopic: A property of a material that causes it to readily absorb and retain moisture.

Latent Heat: Heat given off or absorbed in a process without changing either temperature or pressure.

Manometer, U-Tube: An instrument used to measure pressures; essentially a U-shaped glass tube partially filled with liquid (usually water, mercury, or a light oil) constructed so that the amount of displacement of the liquid indicates the pressure being exerted on the instrument.

Pitot Tube: A double-walled, concentric metal tube used in conjunction with a manometer to measure airstream pressure (see figures in Section VII).

a. The Total Pressure (TP) of the airstream can be measured by connecting the *inner tube* outlet connector to one side of a manometer.

b. The Static Pressure (SP) of the airstream can be measured by connecting the outer tube side outlet connector to one side of a manometer.

c. The Velocity Pressure (VP) of the airstream can be measured by connecting both tube outlet connectors to the opposite sides of a manometer.

Pneumatic Controllers:

Direct Acting: The controller increases output air pressure as the controlled variable increases.

Nonrelay Type: The controller uses a restrictor in the air supply and a bleed nozzle. The sensing element positions a flapper that varies the nozzle opening resulting in a variable air pressure output applied to the controlled device.

Relay Type: The variable pressure resulting from the sensing element, either directly or indirectly through a restrictor, nozzle, and flapper arrangement, actuates a relay device that amplifies the air volume.

Reverse Acting: The controller increases output air pressure as the controlled variable decreases.

Note: All of the above controllers can be one of the following types:

a. *Nonindicating*: The sensing element does not provide a visual indication of the value of the controlled variable.

b. Indicating: The sensing element provides a visual indication of the value of the controlled variable on a suitable scale.

c. Recording: The sensing element is linked to a recording device that provides a permanent record of the controlled variable value.

Pressure Drop: The drop in pressure that occurs with fluid flow across a piece of equipment, balancing device, or flow measuring device due to friction, dynamic losses, and changes in velocity pressure.

Pressure Sensing Elements: Pressure is measured by a bellows, diaphragm, or Bourdon tube either in pounds per square inch or inches of mercury. These elements will respond to pressure above and below atmospheric pressure or the difference between two pressures.

Relative Humidity: The ratio of the existing vapor pressure of the water in the air to the vapor pressure of water in saturated air at the same dry bulb temperature.

Sensible Heat: Heat that changes air temperature without a corresponding increase in moisture content. Dry bulb temperature changes are examples of changes in sensible heat.

Sensing Elements: Devices that measures changes in the controlled variable and produces a proportional effect for use by the controller. (Note: The controlled variable is the condition being controlled, such as temperature, humidity, or pressure.)

Set Point: The desired value of the controlled variable at which the controller is set to operate.

Static Air Horsepower: The value calculated by multiplying the two measured quantities of static pressure in inches of water and the flow rate in cfm (cubic feet per minute) at a diffuser, then dividing this quantity by 6356 (a constant).

Static Efficiency: The ratio of the Static Air Horsepower to the Brake Horsepower of the fan.

Static Pressure: The measure of the potential energy available to produce flow and to maintain that flow again resistance. This pressure is exerted equally in all directions.

Tachometer: An instrument used to measure the speed at which a shaft or wheel is turning (usually in rpm). These devices are made with both dial and electronic readouts.

Temperature Sensing Elements:

Bimetal: Two strips of metal with different coefficients of thermal expansion that bend and change position with a temperature variation.

Remote Bulb: A sealed bellows or diaphragm with a bulb or capsule attached by a capillary tube in which the entire system is filled with a vapor, gas, or liquid. A change in temperature at the bulb results in a change of pressure or volume through the tube to the bellows.

Resistance: A wire with electrical resistance that changes with a temperature change.

Rod-and-Tube: A high expansion metal tube with a low expansion rod inside that has one end attached to the rear of the tube. The tube changes length with a temperature change, causing the free end of the rod to move.

Sealed Bellows: A change in temperature causes a change in pressure or volume of a vapor, gas, or liquid filled bellows that results in a change in force or movement.

Thermostats: Thermostats and humidistats are those controllers that have the sensing elements and controller functions in one device.

Day-Night: The thermostat controls at a reduced temperature at night. It may be changed from day to night operation by a manual or time switch. Some electric types have a clock and switch built into the thermostat.

Dew Point: The thermostat is designed to control from dew point temperatures.

Heating-Cooling: The thermostat reverses its action. It is used to actuate controlled devices such as valves or dampers that regulate heating at one time, and cooling at another.

Multistage: The thermostat operates two or more successive steps in sequence.

Submaster: The thermostat has its set point raised or lowered over a predetermined range in accordance with variations in output from a master controller.

Wet-Bulb: The thermostat is used for humidity control with proper control of the dry-bulb temperature.

Total Air Horsepower: A value calculated by multiplying the two measured quantities of total pressure in inches of water and the flow rate in cfm at a diffuser, then dividing this quantity by 6356 (a constant).

Total Efficiency: The ratio of the Total Air Horsepower to the Brake Horsepower of the fan.

Total Pressure: The amount of energy that must be supplied to the duct system to maintain airflow. The sum of the static pressure and the velocity pressure at the point of measurement.

Transducer: A device that converts electrical signals to pneumatic output or vice versa.

Valve Operators:

Electric Motor: An electric motor operates the valve stem through a gear train and linkage.

a. Unidirectional: For two position operation. The valve opens during one-half revolution of the output shaft, and closes during the other one-half revolution.

b. Spring Return: For two position operation. Electric energy drives the valve to one position and holds it there. When the circuit is broken, the spring returns the valve to its normal position.

c. Reversible: For floating and proportional operation. The motor can run in either direction, and can stop in any position.

Pneumatic: This operator consists of a proportional control, spring-opposed, flexible diaphragm or bellows attached to the valve stem so that an increase in air pressure moves the valve stem and simultaneously compresses the spring.

Solenoid: A solenoid consists of a magnetic coil operating a movable plunger. When the coil is energized, the plunger is lifted and opens the valve.

Velocity Pressure: The measure of kinetic energy resulting from the flow of the air. This pressure is exerted in the direction of flow only.

Voltmeter: An instrument used to measure voltages and electric currents; the clamp-on type is most commonly used for single-phase and three-phase motors.

Volumetric Airflow: The volume of air measured in cubic feet that will flow over a specified amount of time measured in minutes (cfm).

Wet Bulb Temperature: An air temperature measurement that can be used to determine the relative humidity of air. The thermometer bulb is encased in a wick soaked with distilled water.

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